Chapter 8
Nutritional Manipulations to Optimize Productivity During Environmental Stresses in Livestock

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Abstract Environmental stresses have huge impact on the production performance of livestock. Stress can be biotic or abiotic in nature. All animals perform better at thermoneutral zone, which are conducive for health and optimum performance. The upper and lower critical temperature is the point at which heat and cold stress begin to affect the animal, respectively. Apart from thermal stress, farm animals are also subjected to other types of stresses such as nutritional, walking, and transportation stress. The severity of the stress becomes pronounced when they occur simultaneously (multiple stresses), resulting in lowered performance and huge production losses. Farm animals try to cope up with stress to some extent by undergoing physiological and behavioral adjustment. Under these conditions livestock needs to be insulated against environmental stresses by providing optimum nutrition, proper managemental practices, and health care. Adverse environments can increase the nutritional requirements of animals directly, or they may reduce the supply of quality feed. Under these circumstances concerted effort must be taken to harmonize the welfare of animals by reducing environmental stress of food animals by nutritional manipulation and managemental practices. Further studies are required to have a clear understanding of these associations at a mechanistic level to fully exploit the potential of nutritionally manipulated production and reproduction in livestock. It is hoped that this approach will be valuable in gaining a thorough

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understanding of adjusting the nutrient requirement to deal with existing environments and will therefore aid in developing rational managerial decisions to optimize productivity in livestock.

Keywords Environmental stress · Livestock production · Nutritional management

Contents

8.1 Introduction

Livestock plays a pivotal role in the agricultural and rural economies of developing countries such as India. Optimized livestock production depends on many factors such as genetic potentiality of the animals, environmental and climatic factors, health status, nutrients' availability, and other factors. Livestock production, under both intensive and extensive systems, is subjected to so many stresses, wherein livestock undergoes different types of physiological adjustments to cope with stressful conditions. Production is drastically reduced in the periods of stress and requires managemental interventions both in terms of optimum nutrition and health care. Stress can be defined as the cumulative detrimental effect of a variety of factors on the health and performance of animals. The stress in animals can be of abiotic and biotic origin. Abiotic stress is defined as the negative impact of non-living factors on the living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect the population performance or individual physiology of the organism in a significant way. Biotic stresses include living disturbances such as pathogenic microorganism, whereas abiotic stress factors, or stressors, are naturally occurring, often intangible, factors such as intense sunlight or wind that may cause harm to the plants and animals in the affected area. Abiotic stress is essentially unavoidable and affects both animals and plants. Abiotic stressors are most harmful when they occur together in combinations with other abiotic stress factors. Direct stresses result from temperature, solar radiation, humidity, rainfall, and wind velocity whereas indirect stresses comprise of those which affects the supply and availability of feed, and are determined by climatic and other factors which affect the growth of the plants that animals eat.

For livestock, the most stressful of all the abiotic stressors is heat, followed by cold. Many species are unable to regulate their internal body temperature. Even in those species that are able to regulate their own temperature, it is not always a completely accurate system. Temperature determines metabolic rates, heart rates, and other very important factors within the bodies of animals, so an extreme temperature change can easily distress the animal. Homeothermic animals are able to maintain a relatively constant core temperature by balancing the heat gained from metabolism against that gained from or given to the environment. This heat balance is achieved through the concerted effects of physiological, morphological, and behavioral thermoregulatory mechanisms. When the rate of heat loss from the body surface is very high it may lead to hypothermia and when it is very slow it leads to hyperthermia. These two conditions are not well tolerated by the body for an extended period. Under most conditions, there is a continual net loss of sensible heat from the body surface by conduction, convection, and radiation, and under all conditions there is a continual loss of insensible (evaporative) heat from the respiratory tract and skin surface. Thus homeostasis is maintained by the body.

High environmental temperature reduces productive and reproductive efficiency of livestock to a significant extent. There are reports which suggest that when thermal stress is coupled with nutritional stresses, it had severe impact on the productive and reproductive functions in contrast to subjecting to either thermal or nutritional stress separately (Sejian et al. 2010a, b). Most of the studies carried out in controlled condition (controlled-environmental chambers) have established upper critical temperatures for a number of production traits, which fall between 24 and 27°C for most traits and species of livestock. Upper critical temperatures in general will vary depending on several factors such as degree of acclimatization, rate of production (growth or lactation), pregnancy status, air movement around the animals, and relative humidity. Research conducted in controlled environment chambers has been valuable in establishing the basic parameters of stress. However, application of such information to field conditions is often difficult because of wide diurnal variations in ambient temperature and relative humidity, at one hand, and other aspect of the animals' environmental intrinsic compensatory mechanisms on the other hand. Under these conditions livestock needs to be protected against environmental stresses by providing optimum nutrition, proper managemental practices, and health care. Adverse environments can increase the nutritional requirements of animals directly, or they may reduce the supply and quality of the feed. Livestock

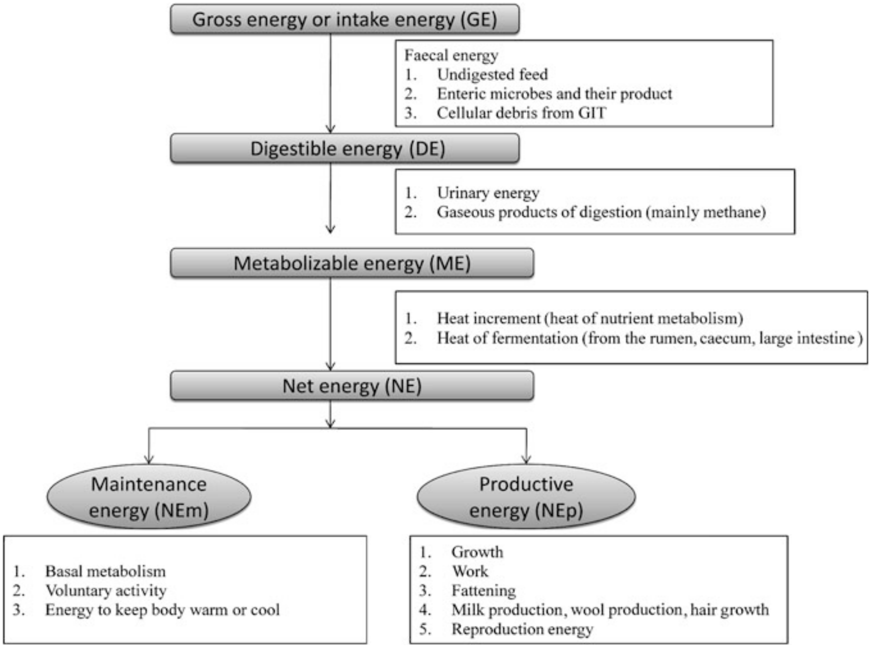

Fig. 8.1 Schematic representation of energy utilization by farm animals. This figure represents the pathways by which the gross energy or feed intake is converted to both maintenance energy and productive energy

production in adverse environments can be limited far more by these indirect effects than by an inability of the stock to maintain homeostatic equilibrium. Under these circumstances concerted effort must be taken to harmonize the welfare of animals by reducing environmental stress of food on animals through nutritional manipulation and managemental practices. A brief discussion of various stresses that are encountered in farm animals, their effect in production, and ameliorative measure are elaborated in this chapter.

8.2 Basic Concept of Thermoneutral Zone and Thermoregulation of Livestock

To have a better understanding of the different stressors that livestock species encounter during the course of production, it is imperative to become acquainted with the processes pertaining to the utilization of dietary energy, since the ambient temperature has a major impact on the energy metabolism of food producing farm animals. Some of the energy terminologies such as gross or intake energy, digestible energy, metabolizable energy, and net energy are commonly used when energy metabolism of farm animals is discussed (Fig. 8.1). Intake energy/gross energy is the combustible energy ingested per day and is determined from the combustible energy density of the feed, its opportunity for ingestion, and the appetite of the animal. Feed is not completely digested or absorbed; therefore, the gross energy (GE) of a food or other material provides no clue about the amount of energy available for livestock production. The amount of digestible energy is more useful for this purpose and can be defined as that portion of feed energy consumed which is not excreted in the feces. Similarly, metabolizable energy (ME) can be calculated by subtracting from the intake energy loss occurring in feces, urine, and gaseous product of digestion. Therefore, ME intake is that which is available to an animal for maintenance and productive function (Net energy). Further, the maintenance function involves the utilization and oxidation of ME for basal metabolism, voluntary activity, and for combating external stressors. The productive function is involved for growth, milk production, fattening, hair and wool production, reproduction, and storage.

Physiological processes in the body are associated with heat production, which is the sum total of non-productive energy utilized by the animal and of the energy "lost" in the course of converting the dietary nutrients. The non-productive energy is used for maintenance of essential physiological processes such as maintenance of the body temperature, the nervous system, organ functions, ion pumping, energy requirement for minimal activity, etc. The total amount of heat produced in the course of digestion, excretion, and metabolism of nutrients is called heat increment. Within a certain range of ambient temperature and besides unvarying feed and nutrient intake, the total heat production of the animal remains constant. This temperature range is called the thermoneutral zone (TNZ) and can be defined as the range of effective ambient temperature (Ames and Ray 1983) within which the heat from normal maintenance and productive functions of the animal in non-stress situations offsets the heat loss to the environment without requiring an increase in rate of metabolic heat production. In a thermoneutral environment, the heat production of the animal is at the minimum, and thus the dietary energy can be used for production (growth, egg and milk production) purpose efficiently (Johnson 1987). The lower critical ambient temperature range point and the upper critical ambient temperature range point define the limits of the TNZ (Robertshaw 1981). Generally, the TNZ ranges from lower critical temperature (LCT) to upper critical temperature (UCT) and depends on age, species, feed intake, diet composition, previous state of temperature acclimation or acclimatization, production, specific housing and pen conditions, tissue insulation (fat, skin), external insulation (coat), and behavior of an animal (Yousef 1985).

Unfavorable temperature (extreme cold or hot) often leads to an increased rate of heat production by the animal (more loss of energy), thereby less energy is available for production at the same level of energy intake, and the efficiency of energy utilization decreases. The upper and lower critical temperatures for different animal species and age groups are presented in Tables 8.1 and 8.2. The species, age, and body condition of the animals all have a significant influence on the critical temperature (Yousef 1985), but other environmental factors affecting their thermal sensation and heat dissipation, such as air velocity and air humidity,

Table 8.1 Lower critical temperature for different farm animals

Species	Body weight (kg)	Lower critical temperature (°C)	References
Dairy cows	600	−22	Charles (1994)
Beef cattle	400	−4	Charles (1994)
Veal calf	100	−14	Webster (1981)
Pig, fattening	20	21	Bruce (1981)
	40	19	Bruce (1981)
	60	17	Bruce (1981)
	80	16	Bruce (1981)
	100	16	Bruce (1981)
Sow	200	18	CIGR (1984)
Laying hen	2	12	CIGR (1984)
Broiler chicken	1	18	CIGR (1984)

Table 8.2 Upper critical temperature for different farm animals (FASS 2010)

Species	Body weight (kg)	Upper critical temperature (°C)
Dairy cow	–	24
Newborn dairy calf	–	−4
Lactating sow with piglets	–	26 for Sow
Prenursery	3–15	32
Nursery	15–35	26
Growing pigs	35–75	25
Finishing pigs	70–100	25
Sow, boar	>100	25
1-day old chicken	–	35
Finishing broiler	–	26
Laying hen	–	27–29

are also crucial. Increasing the airflow improves the efficiency of evaporative cooling, but higher humidity has the opposite effect. In cold and humid conditions, the heat conductivity of wet hair increases thus making the animal more sensitive to the lower ambient temperature.

Thermoregulation is the ability of the animals to maintain their body temperature in cold or hot environments, consisting of behavioral, physiological, and anatomical responses that affect energy metabolism. Moreover, in homoeotherms it is achieved by physiological and behavioral adjustments which involve the musculature, skin, sensory capacities, hypothalamus, and endocrine glands. Under thermal stress, animals exhibit anorexia, body extension, gasping, languor, lethargy, excessive drinking, bathing, decreased locomotor activities, group dispersion, and shade seeking (Hafez 1964). When animals are exposed to cold they show body flexure, huddling, hyperphagia, extra locomotor activities, depressed respiration, and nest building. Species and breed differences in the behavioral adjustments to unfavorable climates are related to habitat, morphological characteristics of body covering, degree of physiological adaptability, degree of physiological immaturity at birth or hatching, and the number of young. In a cold environment, the rate of oxidation increases, in other words, the body "burns" more nutrients, thus boosting its heat production, in order to compensate for the higher heat loss caused by the lower ambient temperature. Shivering is a tool aiding this process; since the energetic efficiency of muscle work is low, the resulting heat production is quite significant (Young et al. 1989). If heat loss exceeds heat production, the result will be hypothermia and ultimately death will occur. The thermoregulatory mechanisms of newborn and young animals (swine and poultry species) are poorly developed; therefore, in the cold environment there is every chance of increases in the number of mortalities (Mitchell and Kettlewell 1998).

The maintenance energy requirement of animals increases in a cold environment, which reduces the amount of energy available for production (Mader 2003). For example, a thin cow requires more energy for maintenance than fat cows. The more subcutaneous fat a cow has, the greater the ability to withstand colder temperatures. Cows that lose weight prior to calving can end up with weaker calves and poorer rebreeding rates. However, higher use of non-productive energy is not the only factor reducing the amount of energy available for production. Another contributing factor is the poorer digestibility of nutrients caused by the low ambient temperature (Kennedy et al. 1982). This means that in cold temperatures higher energy consumption is associated with a relatively lower energy supply. Higher feed or energy intake can help the animals to compensate for this lower energy supply to a certain extent (Galyean and Defoor 2003). From a practical perspective higher temperatures are much more hazardous for growing/finishing and breeding animals than a cold environment. Temperatures exceeding the higher critical level compromise animal performance not only by changing the energy and nutrient metabolism, but also by upsetting the body homeostasis, with detrimental consequences both for immune competence and for product quality. In general, livestock with high production potential are at greatest risk of heat stress, thereby requiring the most attention (Niaber and Hahn 2007). Temperature-humidity index (THI) could be used as an indicator of thermal climatic conditions. THI is determined by equation from the relative humidity and the air temperature and is calculated for a particular day according to the following formula (Kadzere et al. 2002):

$$\mathrm{THI} = 0.72(\mathrm{W} + \mathrm{D}) + 40.6$$

where

W—wet bulb temperature °C
D—dry bulb temperature °C

The principle of THI is that as the relative humidity at any temperature increases, it becomes progressively more difficult for the animal to cool itself. THI values of 70 or less are considered comfortable, 75–78 stressful, values greater than 78 cause extreme stress.

8.3 Different Stresses Encountered in Livestock Production

8.3.1 Cold Stress

Cold stress affects productivity of livestock to a significant extent. When animals are exposed to extreme cold stress, a number of biological processes are initiated to maintain body homeostasis. During extreme cold, the outside temperature falls rapidly and substantial amount of dietary energy may be diverted from productive functions to the generation of body heat. Failure to produce sufficient heat can result in death. A number of factors (environmental and animals) determine the severity of cold stress in animals. Both environmental and animal factors contribute to differences in heat loss from the animal to the environment. Environmental factors include air movement, precipitation, humidity, contact surfaces, and thermal radiation. Factors contributing to differences in animal heat loss from conduction, convection, and radiation are surface area (SA), which include surface or external insulation (EI), and internal or tissue insulation (TI). Evaporative losses are affected by respiration volume as well as SA, EI, and TI.

More often, cold stress leads to the development of secondary changes and possibly disease. With prolonged exposure to even mildly cold conditions, physiological adaptation occurs in animals resulting in an increase in thermal insulation, appetite, and basal metabolic intensity, as well as alterations in digestive functions. Much of the reduced productivity, and in particular the reduced nutritional efficiency, observed in ruminant production systems during the colder part of the year, can be accounted for by these adaptive changes.

Several experiments have demonstrated that during cold stress the ruminant appears to oxidize fat for heat production. The availability of such substrate (acetate, butyrate, and long-chain fatty acids) for oxidation to meet energy requirements for product synthesis and maintenance can, therefore, be influenced by the requirements for heat generation to maintain body temperature. Cold stressed animal will oxidize acetogenic substrate for heat production until 'surplus' acetogenic substrate is totally utilized, after which fat mobilization provides an extra source of metabolic fuel (Graham et al. 1959). Thus, the preferential oxidation of circulating acetate leaves a higher ratio of amino acids (and glucose) in the nutrients available for production than would be available to an animal in its zone of thermoneutrality.

Conversely, an animal that is not required to produce heat, above basal metabolism, will have more acetogenic substrates available for anabolic purposes. The environment can, thus, alter the partitioning of nutrients into productive functions and affect the efficiencies of feed utilization. The design of supplements, to balance diets for ruminants, needs to account for the varying demands for nutrients brought about by the thermal environment of the animal. It is recognized that cold stress in animals often increases voluntary feed intake and rumen turnover rate. In this way, it increases microbial cells moving to the lower tract, thus increasing the P:E ratio in the nutrients available for maintenance or production (Kennedy et al. 1986). The effects of cold stress on performance of livestock are summarized as under.

8.3.1.1 Feed Intake

The dry matter intake of the animals in general is increased during very cold weather. Experiment in sheep that was exposed to cold stress during grazing increased feed intake by 20–40% to compensate for heat loss (Graham et al. 1982). Baile and Forbes (1974) reported increased voluntary feed intake in cold stressed animals which was attributed to the activity of the thyroid gland (Gale 1973). The elevation of thyroid activity resulted in increased ruminoreticulum motility and higher rate of passage of digesta (Gonyou et al. 1979). In contrast to the above, cows consuming only range forage ate less at lower temperature when compared to those kept at warmer winter temperature (Adams et al. 1986). Kartchner (1996) also found that the intake of cows grazing on winter forage was below maintenance during harsh than during mild weather. If energy requirements for grazing and cold environment are considered simultaneously, the relationship between intake and requirement would be less favorable (Adams 1987). Decreased intake of forage results in lesser production of thermoneutral heat which in turn mobilize body fat to bridge energy gap to maintain body temperature (Webster 1974). During cold exposure elevated concentration of glucose and free fatty acids are found in the blood (Young 1975) and these elevated levels of free fatty acids are associated with reduced feed intake (Baile and Della-Fera 1993).

Effect of cold stress on voluntary feed intake (VFI) has also been reported from monogastric animals such as pigs, poultry, etc. When heavy pigs are exposed for an extended period of time to extremely low ambient temperatures (cold stress), feed intake can increase substantially, although feed conversion efficiency (FCE) and average daily gain (ADG) are reduced (Maenz et al. 1994). Cold temperatures also increase the pig's energy requirement, which means additional feed is required to maintain body temperature. Therefore, cold stress usually results in an increase in feed intake. In extreme conditions, feed intake can increase as much as 25%. Pigs exposed to cold stress have a higher metabolic rate (Dauncey and Ingram 1979; Herpin et al. 1987a, b; Herpin and Lefaucheur 1992) and therefore tend to eat more feed to supply the extra energy required for the increased metabolic heat production (Verstegen et al. 1982, 1984). The extra feed consumed for each °C below the lower critical temperature has been estimated at 25 and 39 g/d for growing and finishing pigs, respectively, while ADG is reduced by 10–22 g/d (Verstegen et al. 1982, 1984). It is important to note that these estimates are likely to be lower for pigs housed in larger groups, because of opportunities to huddle and thereby reduce cutaneous heat loss (NRC 1981). However, the extent to which these parameters are affected may depend on the genotype and the severity of cold stress. Younger pigs may be limited in their ability to increase feed intake to meet their nutrient intake requirements because of their limited gut size

(Quiniou et al. 2000). Addition of fibrous ingredients in the diet can also reduce the effects of cold temperatures. Oat and barley contain 7–12% fiber. Dietary fiber will increase the amount of heat produced by the pig and dilute the energy content of the feed. The result is more efficient use of the energy in the feed.

8.3.1.2 Digestibility of Nutrients

Cold stress also appears to affect feed efficiency by both reducing dry matter digestibility and diverting nutrients to heat generation. It has been reported that cold stress reduces dry matter digestibility by 1.8% for each 10°C reduction in temperature below 20°C. In cold stress, much of the reduction in digestibility is attributed to increased passage rate of feed through the digestive tract. An increase in ruminoreticulum motility during cold exposure enhances the rate of passage of small feed particles from the rumen by promoting their mixing, sorting, and fluid propulsion (Gonyou et al. 1979). The digestibility of long, chopped, and ground-pelleted form of hay was significantly reduced in sheep which might be due to increased rate of passage by cold exposure (Nicholson et al. 1980). Graham et al. (1980) indicated that cold temperature increased both fecal and urinary energy losses, resulting in decreased metabolizable energy availability. It is generally accepted that exposure of animals to severe cold decrease digestibility of feeds in confined ruminants (Kennedy et al. 1982) and lower forage digestibility during the periods of cold weather affects the performance of animals due to limited nutrients supply (Adams 1987). Bailey (1964) reported no decrease in digestibility during cold (−10°C) exposure of sheep but there was a slight increase after the animals were returned to a warm (20°C) environment. Horton (1978) did not observe a change in digestibility in sheep with exposure to temperatures of −12 to +l0°C.

The average digestibilities of dry matter, energy, and crude protein was significantly lower in pigs when they were exposed to cold stress (6°C) than pigs exposed to 22°C (Phillips et al. 1982). The effect of ambient temperature on digestion of feedstuffs by growing hogs has also indicated a decrease in energy and nitrogen digestibility when the animals are exposed to cold (Fuller 1965).

8.3.1.3 Milk Production

Severe cold stress affects milk production in dairy cows. If cows are not fed additional feed or the quality does not allow them to eat enough to meet their additional energy requirements, body mass will be “burned” to produce metabolic heat. These cows lose weight as both feed energy and stored fat are diverted to maintain body temperature and vital functions. In this condition cows have lower milk production, increased neonatal mortality, and reduced growth rate in surviving calves. These cows usually have delayed return to estrus and poorer reproductive success. Cold exposure may directly limit the synthetic capacity of the mammary gland by reducing mammary gland temperature (Johnson 1976), or may act indirectly, by affecting the udder's blood supply (Thompson and Thomson 1977). The above adjustments along with changes in endocrine balance induced by cold exposure might significantly alter the metabolism of the mammary gland (Robertshaw 1981) thereby affecting milk production as a whole in cold-stressed ewe. Milk consists of about 90% water and flow of water from blood to milk is probably by osmosis. Lactose is the main osmolar component of milk, rate of milk secretion depends on lactose secretion. As blood glucose is the precursor of milk lactose, glucose uptake by the udder is important for milk secretion (Hardwick et al. 1963). Cold stress alters glucose metabolism in non-lactating animals, and blood glucose concentration, total turnover and oxidation of glucose are increased by cold exposure, thus output of glucose from liver increases (Depocas and Masironi 1960).

8.3.1.4 Body Condition

Dietary energy requirements of beef cattle are influenced by its size and breed, environment, and body condition (Avendaño-Reyes et al. 2010). Because of the insulation value of fat and its low maintenance requirements, fat cows may have lower winter energy requirements than thin cows (Pullar and Webster 1977). Hence, manipulation of body condition may be important economically to cow-calf producers and the ability to deposit external fat may be an important component of an animals' adaptability to cold climate.

If the winter is severe, the pregnant animals may spend whole of the winter using energy to generate heat. If nutrients are shunted to heat production, cattle begin to lose body condition. Cows, and particularly heifers, in poor body condition are at risk for calving-related problems. Therefore, it is imperative to monitor body condition scores (BCS) throughout the winter and to prepare supplements with increased energy, protein, vitamins, and minerals for cold stressed cattle. Cold stressed livestock need more feed just for maintenance than their unstressed counterparts.

8.3.2 Heat Stress

Heat stress can be defined as a group of conditions due to over exposure to or over exertion in excess environmental temperature. The condition includes heat cramp, heat exhaustion, and heat stroke. It is now widely accepted that heat stress is the major cause of lower production and economic loss in sheep and goat, poultry, swine, beef cattle, and dairy cattle. The thermal comfort zone for most animals is between 4 and 25°C. When temperature exceeds 25°C, animals suffer heat stress. In severe cases of heat stress, the deep body temperature (core temperature) rises, animal cells are affected, and production performance is reduced. The effect is more pronounced when the relative humidity is greater than 50%. Thresholds for animal heat stress are important for distinguishing between thermoneutral and thermally challenging environmental conditions. It is a well-recognized biometeorological problem that heat stress has a negative impact on productive performance and ultimately survival of livestock. Accurate estimates of heat stress thresholds are useful for evaluating heat dissipation capabilities, growth rate, feed conversion efficiency, and for comparing management techniques for overcoming the adverse effects of heat stress. For individual animals, the heat stress threshold can be used to characterize sensitivity to hot conditions and possibly identify sentinel animals to represent a group of animals. The current definition of the heat stress threshold emphasizes on the relationship between body and air temperature and the duration of exposure.

The biological mechanism by which heat stress affects production and reproduction in ruminants is partly explained by reduced feed intake, and also includes altered endocrine status, reduction in rumination and nutrient absorption, and increased maintenance requirements (Collier and Beede 1985; Collier et al. 2005) resulting in a net decrease in nutrient/energy availability for production. This decrease in energy results in a reduction in energy balance (EB), and partially explains why cows lose significant amounts of body weight when subjected to heat stress. A reduction in energy intake in lactating cows during heat stress result in a negative energy balance (NEB). Essentially, because of reduced feed and energy intake the dairy cow enters in a bioenergetic state, similar to the NEB observed in early lactation. The NEB associated with the early postpartum period is coupled with increased risk of metabolic disorders and health problems (Goff and Horst 1997; Drackley 1999), decreased milk yield and reduced reproductive performance (Lucy et al. 1992; Beam and Butler 1999; Baumgard et al. 2002, 2006). It is likely that many of the negative effects of heat stress on production, animal health, and reproduction indices are mediated by the reduction in energy balance. However, it is not clear how much of the reduction in performance (yield and reproduction) can be attributed or accounted for by the biological parameters effected by heat stress (i.e., reduced feed intake vs. increased maintenance costs).

Heat stress is one of the major concerns in pork production during summer because pigs do not have functional sweat glands like other livestock species to assist them in efficiently removing body heat. In swine, heat stress causes increased respiration rate leading to increased losses of carbon dioxide from the lungs, resulting in the reduction of partial pressure of carbon dioxide, and consequently the concentration of bicarbonate in the blood. The ensuing lowered concentration of hydrogen ions causes a rise in plasma pH, a condition widely known as alkalosis. Blood alkalosis is considered partially responsible for depressed feed intake and the consequent impaired performance in heat stressed animals. Animals respond to elevated temperature by reducing feed intake, increasing respiratory rate and water consumption, and decreasing activity in an attempt to improve heat loss and minimize the heat generation in the body. As a result of this compensatory mechanism, pigs exhibit poor growth rate and feed conversion, reduced milk production during lactation, impaired fertility, and increased mortality rates. Effects of heat stress in different farm animals are summarized as under.

8.3.2.1 Feed Intake

When cattle were exposed to heat stress a decrease in feed intake and reduction in metabolic rate was observed (Baccari et al. 1983). These responses help the animals in maintaining heat balance (Beede et al. 1983). However, in most temperate breeds of cattle, intake of good quality forages resulted in enhanced metabolic rate and increased requirements for water consumption for intermediary metabolism and thermoregulation (Springell 1968). Voluntary feed intake is affected in feedlot cattle exposed to temperature outside their thermoneutral zone. The reduction in dry matter intake from roughages-based diets becomes pronounced when environmental temperature increase is accompanied with high humidity (Warren et al. 1974; Bhattacharya and Hussain 1993). The feed intake in intensively managed livestock is less affected by heat stress, compared to grazing animals, wherein, during the period of heat stress grazing activity is significantly reduced to maintain thermal balance (Beede et al. 1983).

Moderate heat stress reduces feed intake and growth in young sheep consuming medium quality roughage diets (Dixon et al. 1999). However, exposure to high ambient temperature augments the body mechanism to dissipate body heat, in this situation an increase of respiration rate, body temperature, and enhanced water consumption and a decline in feed intake are evident (Marai et al. 2007). A higher heat increment is caused by the specific dynamic action that accompanies the metabolism of feed which is highest in the case of poor quality, fibrous feedstuffs (Marai et al. 2001). Factors such as water deprivation, nutritional imbalance and nutritional deficiency may exacerbate the impact of heat stress. Sheep, however, are less sensitive to heat stress, when compared to cattle, at a maintenance level of feeding. Research by different workers have reported that dry matter (DM) intake decrease significantly following exposure to heat stress in different breeds of sheep like Croix, Karakul, Rambouillet (Monty et al. 1991), Sardinian and Comisana (Nardone et al. 1991). Similarly, DM intake per kg body weight was reported to be lower and the maintenance requirements were higher at high ambient temperatures. The decrease in concentrate intake by rams was estimated to be approximately 13%, without altering the roughage consumption, when kept at 35°C in a climatic chamber (Nardone et al. 1991). In a recent study, Sejian et al. (2010a) subjected Malpura ewes (a native sheep breed of Rajasthan, India) to either heat stress (40°C; 55% RH) or nutritional stress (restricted feeding) or both in climatic chamber and reported significantly lower feed intake and higher water intake in both heat stress and combined stress group. The intensity of the above effect was very prominent when both the stressors were combined together.

Heat stress affects performance and pork production in swine especially during the summer months because pigs do not have functional sweat glands like other livestock species to assist them in efficiently dissipating body heat. Animals respond to elevated temperature by reducing feed intake, increasing respiratory rate and water consumption, and by decreasing activity in an attempt to improve heat loss and minimize the heat generation in the body. Environmental temperature has a marked effect on both VFI and feeding patterns (Quiniou et al. 2000). In growing pigs, VFI is reported to decrease curvilinearly with increasing environmental temperature while the size of meals is reduced (Collin et al. 2001). For each degree increase in temperature, a reduction in daily feed intake (462 g/d) was observed in multiparous sows that were reared in warm (23°C; RH: 93.8%) and hot (26.1°C; RH: 93.7%) seasons (Silva et al. 2009). The reduction in feed intake in hot seasons was attributed to increased relative humidity (RH). Between 25 and 27°C with a 50–60% RH, Quiniou and Noblet (1999) reported a reduction in feed intake equivalent to 254 g/d/°C. The greater daily feed intake reduction per degree Celsius found in their study (462 g/d°C) was related to the effect of the increased humidity observed during their study (85–98%). These results suggest that the negative effect of elevated ambient temperature may be accentuated by the increased RH in a tropical climate.

Marked changes are observed in poultry birds when subjected to heat stress. In poultry production, heat stress can be either acute or chronic. Acute heat stress refers to short and sudden periods of extremely high temperature, whereas chronic heat stress refers to extended periods of elevated temperature. Chronic stress has deleterious effects on birds that are reared on open-sided houses and causes a reduction in feed consumption and increasing water intake. Most of the reduction in feed consumption is due to reduced maintenance requirement. For every increase (1°C) in environmental temperature from 22 to 32°C, feed intake in broiler chicken was reduced by 3.6% (Ain Baziz et al. 1996). This reduction in intake was aimed to avoid increase of endogenous heat production since heat production is high when feed intake increases (Koh and Macleod 1999a, b).

8.3.2.2 Digestibility

Exposure of ruminants to heat stress in some studies has shown to increase digestibilities of dry matter, crude protein, cell solubles, and various fiber fractions, as a result of reduced rate of passage through the gastrointestinal tract and increased mean retention time (Lippke 1975; Warren et al. 1974). The increase in digestibility of feed associated with higher temperatures is probably due to depressed intake, which results in slower rate of passage (Davis and Merilan 1960). Weniger and Stein (1992) also reported significantly higher digestibility and nutrient degradation in the rumen at a high ambient temperature and low relative humidity (35°C and 50% humidity), than at a lower ambient temperature–high relative humidity (30°C and 60% humidity) in adult Merino rams.

While in some experiments the digestibility of DM, CP, ether extract, energy, and metabolizable energy of diets are reported to be depressed when the animals are exposed to high temperatures (Marai et al. 2001). The digestibility was lower when the proportion of roughage was 75% of the total diet in Awassi breed of sheep (Marai et al. 2007). In summer months, the nutrients content of the pasture declines with concomitant increase in higher fiber and lignin and there will be fall in the digestibility of nutrients because of an increase in the lignin or "wood" fiber content in the grasses. Other studies have shown the ability of ruminants to digest roughage-based diet increases in warmer temperatures while it decreases in colder environments (Conrad 1985).

Consistent decrease of protein and amino acid digestibilities of complete diets were observed in monogastrics animals like poultry subjected to heat stress (Wallis and Balnave 1984) and individual feed ingredients (Zuprizal et al. 1993). High ambient temperatures are associated with suppressed nutrient digestibility in poultry (Wallis and Balnave 1984; Sahin and Kucuk 2003). Larbier et al. (1993) observed that heat stress decreased protein digestibility. Bonnet et al. (1997) reported that the digestibility of proteins, fats, and starch decreased with exposure of broiler chickens to high temperatures. In addition, activities of trypsin, chymotrypsin, and amylase decrease significantly at a temperature of 32°C (Hai et al. 2000). The amylase and maltase activities in laying hens and broilers were reported to change under acute heat stress conditions, but not under chronic exposure to heat (Osman and Tanios 1983).

8.3.2.3 Growth Rate

Heat stress has appreciable effect on the growth performance of farm animals. Prolonged exposure of livestock to high temperatures negatively affects growth of livestock. For instance, in finisher pigs the optimum temperature range lies between 10 and 23.9°C (Myer and Bucklin 2001), and temperatures above 23.9°C decrease voluntary feed intake and pig growth (Kouba et al. 2001). Changes in growth performance with heat stress appear to be related to lower feed intake rather than changes in nutrient metabolism. Pigs exposed to heat stress (37°C) had lower (31%) ADG, lower (23%) feed intake, and 34% higher average daily water intake, compared with those in the non-heat stress conditions (Song et al. 2011). The ADG of crossbred wether lambs were significantly reduced when they were exposed to high temperature of 35°C. Reduced ADG during thermal stress occurs because maintenance requirement for energy increases during both cold and heat stress while energy intake declines during heat and does not increase as rapidly as maintenance costs during cold (Ames and Brink 1977).

Growth in animals is defined as increase in live body mass or cell multiplication and is controlled both genetically and environmentally. The available nutrients, hormones, and enzymes, as well as, elevated ambient temperatures are considered as some of the environmental factors that can influence ADG (Hafez 1987; Habeeb et al. 1992). The birth weight of lamb (temperate sheep breeds) showed a linear decrease when their dams were maintained for generations together in hot, semi-arid locations. Such a decline was shown from the sixth to the eleventh generation in Rambouillet lambs, while the reduction was apparent from the second generation in Suffolk lambs. In Merino and Dorset Horn, lamb birth weights showed no such a decline up to the sixth and third generations, respectively (Singh and Karim 1995).

The average daily gain of lambs are lower in summer than in winter, as well as in a psychrometric chamber (30–40°C) compared to a shelter (20–30°C), for Suffolk sheep (Marai et al. 1997; Padua et al. 1997). The effects of higher ambient temperature on growth performance can be explained in terms of a decrease in anabolic activity and the increase in tissue catabolism. This decrease in anabolism is essentially caused by a decrease in voluntary feed intake of essential nutrients. The decrease, especially ME for both body maintenance and weight gain, causes a loss in the production per unit of feed (Marai et al. 2007).

8.3.2.4 Milk Yield

High environmental temperature (heat stress) reduces milk yield in dairy cows especially in animals of high genetic merit. Johnson et al. (1962) demonstrated a linear reduction of dry matter intake (DMI) and milk yield when THI exceeded 70. The reductions were −0.23 and −0.26 kg/day per unit of THI for DMI and milk yield, respectively. Nardone et al. (1992) induced heat stress in climatic chambers and observed a decrease in milk yield to the tune of 35% in mid-lactating dairy cows and of 14% in early lactating dairy cows (Lacetera et al. 1996) kept under heat stress conditions. The optimal ambient temperature of dairy cows falls between 5 and 15°C. Over 15°C the animals start to sweat, although they are still able to maintain the equilibrium between heat production and heat dissipation. Heat dissipation by sweating gradually increases and although it becomes quite intense above the upper critical temperature (25°C) the cow is no more able to maintain the heat balance at such high temperatures. Kadzere et al. (2002) reported that on days of heat stress the amount of water lost through evaporation in dairy cows may be up to or even exceed the amount of water excreted in the milk. The high rate of water loss stresses the importance of water supply for dairy cows at high temperatures.

Milk production traits in ewes seem to have a higher negative correlation with the direct values of temperature or relative humidity than THI. The values of THI, above which ewes start to suffer from heat stress, seem to be quite different among breeds of sheep (Finocchiaro et al. 2005). Solar radiation seems to have a lesser effect on milk yield, but a greater effect on yield of casein, fat, and clot firmness in the milk of Comisana ewes (Sevi et al. 2001).

8.3.2.5 Egg Production and Meat Quality

During the period of extreme environmental temperature the production and quality of egg is affected in poultry. It has been observed that temperature and moisture of air are two major environmental factors controlling the heat stress of livestock (Bouraoui et al. 2002; St-Pierre et al. 2003). Heat loss in poultry is limited due to feathering and the absence of sweat glands. When the temperature and RH exceed the comfort level of a bird, it loses the ability to efficiently dissipate heat. This leads to physiological changes that are accompanied by a change in hormonal status and a reduction in feed intake to reduce metabolic heat production (Teeter et al. 1985) and lower growth rate as well as reduce feed efficiency (Geraert et al. 1996). Heat stress to different extents adversely affects egg size, laying percentage, mortality, body weight gain, and egg shell durability (Sterling et al. 2003; Lin et al. 2004; Franco-Jimenez and Beck 2007) in laying birds. The combination of high atmospheric temperature and relative humidity increase the severity of heat stress and results in the excessive generation of reactive oxygen species or free radicals due to increased metabolism in birds (Ramnath et al. 2008).

Heat stress has long been recognized as one of the major environmental factor influencing meat quality (Mckee and Sams 1997). Kadim et al. (2004) found strong negative effects of the hot season (34.3°C and 48.8% relative humidity) on the quality characteristics of beef meat, wherein, these authors reported higher pH, lower shear force value, and darker meat of *longissimus thoracis* muscle in heat stressed beef cattle when compared with muscle samples collected during the cool season. Sayre et al. (1963) reported stress-susceptible pigs that were subjected to heat stress (42–45°C for 20–60 min) prior to slaughter-developed pale, soft, and exudative (PSE) meat characteristics. Birds become vulnerable to heat stress at temperature above 30°C (Ensminger et al. 1990). Especially in the hot regions, heat stress is of major concern for the poultry industry because of the resulting in poor growth performances (lower body weight gain and carcass yield) and high mortality rates (Nardone et al. 2010). Selection of broiler chicken for rapid growth rate has been associated with increased susceptibility to heat stress (Berong and Washburn 1998; Cahaner et al. 1995). Northcutt et al. (1994) found that chickens that were subjected to heat (40–41°C for 1 h) and preconditioned (3 d at 35–36°C for 3 h) exhibited PSE meat characteristics. Environmental temperatures above 30°C can cause a reduction in feed intake, body weight, carcass weight, carcass protein, and muscle calorie content in broiler (Tankson et al. 2001). Feng et al. (2008) observed significant decrease of initial pH, drip loss, and shear force of breast muscle in heat stressed broilers. However, Northcutt et al. (1994) found that turkeys subjected to 30°C for 1 h had lower initial pH after slaughter than controls, but they did not differ in lightness or water-holding capacity from the controls. In addition, Froning et al. (1978) found that turkeys exposed to immediate pre-slaughter heat stress did not exhibit PSE meat characteristics. Stress is the factor which accelerates metabolism and quick exhaustion of muscle glycogen supplies.

8.3.2.6 Metabolism

During the heat stress a significant alteration in the metabolic activity takes place in the body of heat stressed animals. Vasodilatation of the blood vessels occurs, facilitating increased blood flow and thereby, helping in dissipation of excessive heat load from the body (Thatcher and Collier 1982). These changes cause reduction of blood supply to the internal organs, including the ruminant fore-stomach (von Engelhardt and Hales 1977), as the blood flow to the digestive system is greatly influenced by the level of feed intake (Lomax and Baird 1982), a factor which is influenced by heat stress (Attebery and Johnson 1969).

Another significant change encountered during high environmental temperature is the release of stress hormones. Glucocorticoids level increase many fold during the heat stress (Collier et al. 1995). Association between circulatory glucocorticoids and proteolytic activity in the digestive tract of animal results in increased urinary nitrogen and creatinine excretion (Tepperman 1980), which is indicative of greater protein catabolism and lower nitrogen retention in cattle that were maintained at high temperature of 48°C (Colditz 1972). Bhattacharya and Hussain (1993) concluded that heat stress resulted in a reduced metabolizable energy and nitrogen retention. A reduction in the level of plasma triiodothyronine, decrease in body weight gain, and poor feed conversion efficiency was reported in heat stress animals (Baccari et al. 1983).

Heat stress also results in the loss of large proportion of minerals such as sodium, potassium, magnesium, and chloride ions from the body (Jekinson and Mabon 1973). At high environmental temperature (40°C), Collier et al. (1995) reported a 28-fold increase in the urinary excretion of potassium in heat stressed cows compared to cows that were maintained at 15°C. Addition of dietary potassium (Mallonee et al. 1993) and sodium salts (Schneider et al. 1986) in the diet of heat stressed animals showed increase dry matter intake and milk production in the heat stressed cows.

8.3.3 Nutritional Stress

Nutrition plays an important role in the production performance of farm animals. Superior genetic potentiality of livestock is often veiled due to inadequate nutrition resulting in lower growth rate, milk yield, meat production, and other performances. Nutritional factors such as excessive or insufficient nutrition adversely affect the entire body function. Grazing animals in arid and semi-arid regions are generally subjected to periods of undernutrition during extreme hot environment due to nonavailability of feed and poor pasture conditions caused by lower availability of nutrients, which in turn results in low productivity. The animals suffer severe nutritional stress in the dry-season when the natural pasture is of low nutritional value and usually in scarce supply. During this time of the year, animals also waste a lot of energy, as they have to walk long distances in search of food and water. As a result of these dry season and adverse conditions, animals lose weight, body condition and have low milk yields, low conception rates, and increased calf mortalities, all of which culminate into heavy economic loses to the small holder farmers.

Sheep and goats due to their inherent grazing habit are often susceptible to nutritional stress. Extensive rearing of sheep and goats in most of the arid and semi-arid regions is characterized by grazing during day hours and housing of the animals during night time, with possible supplementation of concentrate mixtures and of straw or hay. In extensive production systems, the animals are free to move within a habitat that allows them to best perform their physiological and behavioral functions. However, grazing can sometimes also adversely affect the well-being of animal due to seasonal fluctuations of herbage quantity and quality, thus the grazing animals are usually subjected to a temporary nutritional stress. If the nutritional stress occurs during mating season, it can reduce sheep fertility (Rassu et al. 2004).

In the areas where sheep and goat breeding is more diffused, late spring and summer are characterized not only by poor grass availability and palatability but also by a marked reduction of its protein content (Negrave 1996). Therefore, grazing animals in extensive rearing can face nutritional imbalance/nutritional stress during this period of the year, with the alteration of rumen fermentation and protein synthesis, which affects their well-being and negatively influences milk, fat, and protein content. When goats graze in poor meadows with excessively fibrous vegetation, under bad weather conditions, and with limited time for herbage ingestion, they may show decreased milk production (Fedele et al. 1993). Pulina et al. (2006) found that short-term feed restriction strongly reduced milk yield and increased milk fat content in Sarda dairy ewes. Undernutrition significantly affected the milk fatty acid profile, as a consequence of body fat mobilization. Underfed ewes showed higher milk somatic cell count, indicating a metabolic stress of the animal and its mammary gland. Nutritional stress induced by restricted feeding (30% lower than control) and high environmental temperature (40°C) resulted in lower body weight gain and body condition score in Malpura ewes (Sejian et al. 2010a).

Young pigs can be susceptible to nutritional stress especially when they are weaned. This nutritional change is involuntarily added to the pig's sociological, environmental, and immunological stresses at weaning. In rapidly growing pigs, the rate of weight gain can exceed the development of the control and adaptation systems of the body. As a result, the body resistance to disease is decreased while the susceptibility of the animal to infection increases. Young animals are more sensitive to nutritional stress because their adaptive mechanisms are poorly developed. Over feeding and changing feeding patterns can cause stress and result in ulcers in pigs. Poor quality drinking water containing high levels of dissolved minerals, including sulfates, increases the incidence of diarrhea and worsens post-weaning growth in piglets.

8.3.4 Walking Stress

Livestock in tropical regions are subjected to walking stress, wherein, these animals have to travel long distances in search of grazing pasture. Small ruminants like sheep and goat spend a sizeable amount of energy in the walking activity, especially in hot summer. In contrast, temperate zone sheep do not suffer from heat stress, which is the main worry in the humid tropics; consequently, at least climatically, sheep adjust satisfactorily. Domestic livestock commonly spend around 7–12 h/day in grazing, which include time spent for searching as well as for consuming forages (Burns and Sollenberger 2002). As the grazing time increases, more energy is used for activity and less for production purpose, thus, the minimum time that results in adequate dry matter intake is considered optimum. Grazing time of livestock in pasture depends on the ease of ingesting, which varies with accessibility of plant parts, availability of total forages, and quality of the consumed diet (Burns and Sollenberger 2002). Grazing time is generally lowest when forage is abundant and of good quality and highest when forage is of low quality or availability is limited. Grazing time may fall when grazing animals are in a severe caloric deficit and forage availability is severely limited, thus contributing even further to decline in forage intake (Hodgson 1986).

The energy expenditure of locomotion contributes significantly to the energy requirement of animals in free-living conditions and must be included for accurate evaluation of the energy needs of the grazing animal. Most of the increase in energy expenditure of physical activity results from grazing and locomotion costs, whereas the contribution of other activities is usually considered to be negligible. Grazing animals have an extra daily maintenance requirement due to the demand of energy for the physical activities of forage intake and walking. However, when numbers of stressors such as heat stress, nutritional stress, and walking stress occur simultaneously, then the severity of the stress is increased and productive and reproductive performance of the animals are severely affected. Walking stress significantly altered the growth, physiological response, and hematobiochemical changes in the Malpura ewes that were subjected to walking for a distance of 14 km (Sejian et al. 2011) in semi-arid environment. In their study, there was a significant increase in respiration rate, rectal temperature, and plasma cortisol level, which was indicative of stress.

8.3.5 Transportation Stress

Stress associated with transport occurs in food animals essentially in commercial agriculture and to a lesser extent in the rural sector. Transportation stress may be more or less severe, depending on a number of different stress factors involved. The major stress factors in livestock transportation may be classified as noise, vibration (Dobson 1987), lack of exercise (Hutcheson and Cole 1986), prolonged standing (Lambooy and Engel 1991), and environmental temperature and humidity (Dantzer 1982). Animals may be transported for marketing, slaughter, restocking, from drought areas to better grazing areas and for a change of ownership. Typically, methods used to move animals are on hoof, by road (motor vehicle), by rail, on ship, and in some cases by air. Majority of livestock in developing countries, in general, are moved by trekking on the hoof for short distances and by road or rail, when transportation involves long distances. Transport of livestock is undoubtedly the most stressful (Maria et al. 2004) and injurious stage in the chain of operations between farm and slaughter house and contributes significantly to poor animal welfare, loss of production, and poor meat quality. Transportation of food animals is of great concern due to several reasons (Knowles et al. 1999a, b; Hartung 2003). These are:

1. Cause severe stress in animals, if welfare conditions are not provided.
2. Stressful transportation may adversely affect meat quality.
3. There is the risk of spread of infectious diseases over large distances.
4. Animal health can be impaired by various pre-transport and transport conditions.

The above conditions may cause injury, reduce performance, increase in morbidity and mortality rate, and consequently substantial economic losses due to loss of live weight and poor meat quality (Knowles et al. 1999a; Fazio and Ferlazzo 2003; Minka and Ayo 2007). Transportation exposes food animals to stress, resulting in increased morbidity and mortality. During transport the hypothalamo-pituitary-adrenal axis is activated by stressors (noise, vibration, prolonged standing, lack of food and water, and environmental temperature) resulting in increased concentrations of plasma catecholamines and cortisol (Sconberg et al. 1993). Catecholamines and cortisol are essential components of adaptation to stress. Deprivation of food and water for quite a long time during transportation further depresses the condition of the already stressed animal. The transported food animals are subjected to concomitant action of transportation and heat stress factors. These deleterious stress factors significantly weaken the body resistance and the affected animals become vulnerable to diseases.

8.4 Nutritional Management of Heat Stress in Domestic Animals

8.4.1 Dairy Cows

The primary impact of heat stress in dairy cows is a significant reduction in voluntary feed intake. Water intake is closely related to DMI and milk yield and its intake is increased by 1.2 kg/°C increase in minimum ambient temperature, but regardless of rate of increase it is obvious that abundant water must be available at all times under hot conditions. Thus water is the most important nutrient for dairy cow. Several nutritional strategies need to be implemented during this period and these include reformulations to account for reduced DMI, higher maintenance costs, and metabolic heat production from various feedstuffs (West 2003). The maintenance requirement of lactating dairy cows increases substantially as environmental temperature increases; therefore, the frequency of feeding may be increased so as to increase DMI. During the period of heat stress, the diurnal temperature rises to a significant level and animals are often reluctant to take feed in an effort to reduce heat production and feeding in the early morning or late evening hours can be practiced to reduce total heat load on the animal (Staples 2007). As the intake of DM generally declines with hot weather, effort should therefore be made to increase the nutrient density of the diet. Energy density can be increased by supplementing extra grain or fat in the diet and a reduction in forages. Feeding of dietary fat (rumen protected/rumen bypass) in the concentrate remains an effective strategy of providing extra energy during a time of negative energy balance. Compared to starch and fiber, fat has a much lower heat increment in the rumen and thus provides energy without a negative thermal side effect (Gaughan and Mader 2009).

Nutritionists often increase the energy or protein density of the ration during prolonged periods of heat stress. Caution should be exercised if increasing protein levels during hot weather since there is an energetic cost associated with feeding of excess protein. Feeding of excess N above requirements reduces ME by 7.2 kcal/g of N (Tyrrell et al. 1970). Studies have shown that the energetic cost associated with synthesizing and excreting urea can compromise milk production when feeding excess protein (West 2003). When diet containing 19 and 23% CP were fed to dairy cattle, milk yield was reduced by over 1.4 kg (Danfaer et al. 1980) and the energy cost associated with synthesizing and excreting urea accounted for the reduced milk yield (Oldham 1984). Heat stressed cows do have an extra requirement for dietary or rumen-produced glucose precursors like propionate. However, lower fiber/high fermentable carbohydrate rations may drive propionate, increase energy density, and lower heat increment, but these effects must be balanced with the potential for ruminal acidosis in animals already prone to acidosis due to intake variations and reduced rumen buffering capacity. Consideration should be given not only to the quantity of fermentable carbohydrate but also to the dynamic aspects of starch digestibility in fermented feeds such as corn silage or high moisture corn (Mahanna 2007).

During hot weather, declining DM intake and high lactation demand requires increased dietary mineral concentration. However, alterations in mineral metabolism also affect the electrolyte status of the cow during hot weather (West 2003). Important minerals such as sodium, potassium, and magnesium are lost from the body due to persisting perspiration and in this condition feeding diets with a high dietary cation–anion difference can improve intake in heat stressed cows (Tucker et al. 1988). Cattle utilize potassium (K+) as the primary osmotic regulator of water secretion from their sweat glands. As a consequence, K+ requirements are increased (1.4–1.6% of DM) during the summer, and this should be adjusted for in the diet. In addition, dietary levels of sodium (Na+) and magnesium (Mg+) should be increased, as they compete with potassium (K+) for intestinal absorption. Therefore, feeding elevated levels of potassium (1.5–1.6% of DM), sodium (0.45–0.60% of DM), and magnesium (0.35–0.40% of DM) is also recommended (Staples 2007) as they are the primary cations in bovine sweat. The role of vitamin nutrition in the management of heat stress in dairy cattle has been reported in some studies. Cattle supplemented with niacin (6 g/d) during summer months increased milk yield by 0.9 kg/d compared with controls (Muller et al. 1986). Recent research indicates that the addition of 12 g/day of encapsulated niacin may improve heat tolerance through elevation of cellular heat shock proteins and peripheral vasodilation (Burgos-Zimbelman et al. 2008).

8.4.2 Sheep and Goat

Nutrient requirements of sheep and goat increase during the period of heat stress. During heat exposure, energy requirement of domestic livestock increases because lot of energy is expended during respiratory muscular activity (Linn 1997), sweat gland activity (Shibasaki et al. 2006), and the calorigenic effect of hormones (Gudev et al. 2007). The adjustment of diets by reducing the roughage content, addition of dried beet pulp, and increasing fat content can be a practical approach toward minimizing the effect of heat during heat stress (Lofgreen 1974). Another practical approach can be to reduce the concentrate proportion in the diet, for instance, Moose et al. (1969) found that low-concentrate diets (35%) had lowered heat increment than higher concentrate diets (70%) when fed to lambs and reported that at temperatures above 25°C high heat increment can seriously impair the efficiency of diets containing higher percentages of roughage. Protein requirement during heat stress should be able to meet the need of animals to maintain nitrogen equilibrium (maintenance protein) and that needed for productive function. Ideally, dietary protein exceeding that needed for maintenance is used only for production (growth, wool, or milk); however, growth and other productive functions may be limited by available energy because of increased requirement of energy for maintenance during thermal stress. When energy is limiting, protein may then be catabolized and serve as an energy source (Crampton and Harris 1969).

8.4.3 Pigs

To counter heat stress the foremost mechanism adapted by growing pigs (Quiniou et al. 2000) and lactating sows (Quiniou and Noblet 1999; Renaudeau et al. 2001) is to reduce their feed intake, wherein, to lower internal heat production. Exposure to temperatures above 25°C can be considered as a heat stress situation, especially for lactating cows. The effects are accentuated when the high ambient temperature is combined with a high relative humidity (Renaudeau et al. 2003). In this situation, the best nutritional practice to minimize the negative effects of heat stress on feed intake would be to add supplemental fat to the diet because fat has a lower heat increment than either carbohydrate or protein, and to increase the concentration of other nutrients. Fat has a high caloric density that helps offset lowered caloric intake during heat exposure. The partial replacement of dietary CP by starch is associated with a reduced heat production in pig. Increased dietary fat content has similar effects on heat production and the effects of dietary CP reduction and fat addition are additive (Noblet et al. 2002). Based on these assumptions, it can be hypothesized that low CP diets (and/or fat supplemented diets) would be better tolerated by heat stressed pigs as the effect of heat stress on their energy intake would be attenuated.

Stahly et al. (1979) report an advantage of feeding synthetic lysine instead of natural protein, as it reduces heat increment of the diet. During heat stress, dietary crude protein may require adjustment. The daily feed intake decrease by about 40 g/°C of heat stress, and this is paralleled by a daily gain depression of 10–20 g/°C rise of temperature (NRC 1981). Some researchers have reported that dietary vitamin and mineral concentrations may need to be increased under heat stress conditions. But there is little evidence indicating that total daily requirements of these nutrients are affected by effective ambient temperature. Of course, as high temperatures reduce feed intake, it may be advisable to increase the concentration of certain vitamins and minerals in the diet to compensate. Peng and Heitman (1974) found that dietary thiamine requirement may be greater at 30 and 35°C compared with thermoneutral temperature. Holmes and Grace (1975) found more potassium in the urine of heat stressed pigs, but calcium retention was not affected.

8.4.4 Poultry

As poultry birds are very rapid growing with enhanced metabolic rate, thus they are susceptible to a number of stressors. High environmental temperature often deters optimum intake of feed. Energy intake is the most important nutrient limiting bird performance at high temperatures. Studies have shown that the energy requirement for maintenance decreases by about 30 kcal/day with an increase in the environmental temperature above 21°C. The maintenance energy is lower at higher temperature and most of this energy is wasted in heat dissipation, so the absolute energy requirement is not affected by heat stress. In general, the feed intake changes about 1.72% for every 1°C variation in ambient temperature between 18 and 32°C but when the rise of temperature is much higher (32–38°C), the rate of decline is much more higher (5% for each 1°C). Under these circumstances, corrective measures need to be taken to improve feed intake, which might include the addition of fat in the diet. When 5% fat was supplemented into the diet of heat stressed bird, feed consumption improved by 17% in heat stressed birds (Dale and Fuller 1979). The added fat provides an extra calorific value by decreasing the rate of passage of digesta, thereby increasing the utilization of nutrients (Latshaw 2008). Fats or oils with more saturated fatty acids are preferred in hot humid climates. The concentration of energy should be increased by 10% during heat stress, while the concentration of other nutrients should be increased by 25%. The requirements for protein and amino acids are independent of environmental temperature so heat stress does not affect bird performance as long as the protein requirement is met. As heat stress reduces feed intake, the levels of protein/amino acids therefore need to be increased with the environmental temperature up to 30°C. The supplementation of essential amino acids to a diet with a poor protein quality or amino acids imbalance helps to improve performance by reducing heat increment and the harmful effects of high temperature (Waldroup et al. 1976). In order to maximize nutrient intake, one must consider relatively high nutrient-dense diets, although these alone do not always ensure optimum growth. Relatively high protein (16–18% CP) with adequate methionine (2% of CP) and lysine (5% of CP) level together with high energy level (11.7–12.6 MJ/kg) are usually given to Leghorn hens, in hot weather situations (McNaughton et al. 1977).

Heat stress reduces calcium intake and the conversion of vitamin D_3 to its metabolically active form, 1, 25$(OH)_2$ D_3, which is essential for the absorption and utilization of calcium (Faria et al. 2001). The calcium requirement of layers, particularly older birds, is increased at high environmental temperatures. Therefore extra calcium should be provided at the rate of 1 g/bird in the summer months in the form of oyster shell grit or limestone. Supplementation should be made over the normal dietary calcium level (3.75 g/bird/d) recommended for layers. However, due care should be taken to prevent excessive levels of calcium, as it reduces feed intake. The phosphorus level in diet must not be forgotten as excessive phosphorus inhibits the release of bone calcium and the formation of calcium carbonate in shell gland, thereby reducing the shell quality. Supplementing the diet with 0.5% sodium bicarbonate or 0.3–1.0% ammonium chloride or sodium zeolites can alleviate the alkalosis caused by heat stress. Sodium bicarbonate stimulates feed and water intake and improves shell quality at high environmental temperature (Balnave and Muheereza 1997; Koelkebeck et al. 1993). The body weight gain can be increased up to 9% by addition of these chemicals in the feed of heat stressed broilers. The excretion of potassium through urine is significantly higher at 35°C than at 24°C. The potassium requirement increases from 0.4 to 0.6% with a rise in temperature from 25 to 38°C. A daily potassium intake of 1.8–2.3 g potassium is needed by each bird for maximum weight gain under hot conditions. To compensate for the reduced feed intake under heat stress, dietary allowances for electrolytes (sodium, potassium and chloride) may be increased by 1.5% for each 1°C rise in temperature above 20°C (Balnave and Zhang 1993; Smith 1994).

Additional allowances of ascorbic acid (vitamin C), vitamins A, E, and D_3 and thiamine can improve bird performance at higher temperatures (Ferket and Qureshi 1992). However, the loss of vitamin activity either in premix or in feed during storage particularly at elevated environmental temperature is a prime concern and probably explains the conflicting results on the effects of vitamin supplementation during heat stress. High temperature, moisture, rancid fats, trace minerals and choline speed up the denaturation of vitamins. Vitamin activity in feeds can be maintained by using feed antioxidants, gelatin encapsulated vitamins, appropriate storing conditions and adding choline and trace minerals separately from other vitamins. Ascorbic acid synthesis is decreased at elevated environmental temperature, making it an essential dietary supplement during the summer. The vitamin helps to control the increase in body temperature and plasma corticosterone concentration (Fenster 1989; Pardue and Thaxton 1986). It also improves eggshell quality via its role in the formation of the shell's organic matrix, Supplementation of ascorbic acid (200–600 mg/kg diet) improves growth, egg production, number of hatching eggs, feed efficiency, egg weight, shell quality, and livability during heat stress. The absorption of vitamin A declines at high temperatures. In broiler breeders, a threefold increase in supplementation has been found to be beneficial. Vitamin E protects the cell membrane and boosts the immune system, so additional dietary supplementation may be advantageous during hot weather.

8.5 Nutritional Management of Cold Stress

Many factors may influence the nutrient requirements of animals. Low environmental temperature increases the requirement of nutrients in farm animals. New born calf when subjected to low environmental temperature needs special care as the body energy reserve of new born animal is limited and the body energy stores in the form of fat and glycogen will not last for more than about one day under very cold conditions (Alexander et al. 1975; Okamoto et al. 1986; Rowan 1992). The thermo neutral zone in very young calves ranges from 15 to 25°C. Thus, when the environmental temperature drops below 15°C (LCT), the calf must expend energy to maintain its body temperature, thus the maintenance energy requirement is increased. However, for older calf the LCT may be as low as −5 to −10°C (Webster et al. 1978). Therefore, young calves should be fed extra energy during cold weather to satisfy the proportionate increase in maintenance energy requirements (NRC 2001). This can be done by increasing the amount of liquid diet with additional milk solids or by incorporating additional fat into the liquid diet (Schingoethe et al. 1986; Scibilia et al. 1987; Jaster et al. 1990). However, additional fat in milk replacer or starter decreases starter intake (Kuehn et al. 1994), which negates at least a portion of the increased energy density from fat supplementation.

The energy requirement of dairy cows in low ambient temperature is minimal because of high heat production due to consumption of large amounts of feed (NRC 2001). Even in barns with proper ventilation, it is unlikely that cows will require increased intake of energy to counteract cold environments if they are kept dry and are not exposed directly to wind. Young (1976) summarized experiments with ruminants exposed to cold temperature and reported that an average reduction in DM digestibility of 1.8% units for each 10°C reduction in ambient temperature below 20°C. Much of this lowered digestibility under cold stress was attributed to an increased rate of passage of feed through the digestive tract (Kennedy et al. 1976). Because of the effects of low temperature on digestibility, under extremely cold weather conditions, feed energy values could possibly be lower than expected. But for grazing ruminants lower environmental temperature increases the maintenance energy to a considerable extent because very cold temperature often affects active growth of plants and pasture grasses, a diet based on pasture and browse normally becomes inadequate for grazing ruminants. Though sheep and goats are able to meet their nutrient requirement form pasture but in case of large ruminants like cows, grazing with adequate supplementation of concentrate will meet nutritional requirement of stressed animal.

On the other hand, non-ruminant species, however, including pigs, and poultry require a more highly digestible diet to enable them to thrive and be highly productive. However, if they are kept in confinement, it becomes essential to provide all the important nutrients through diet. All species of livestock have a greater need for better quality feed when they are in full production (milk, eggs) or when they are growing fast. Poultry have increased energy requirements to maintain normal body temperature in cold ambient temperatures. The process of digestion of feed produces body heat and the amount of heat produced (heat increment) will vary according to the nutrient composition of the diet. In cold temperatures it may be desirable to formulate a diet with a higher heat increment and the opposite in hot temperatures.

Exposure of pig to environmental temperatures below its thermoneutral zone affects feed consumption. Conversely, feed consumption increases as environmental temperature is reduced within a moderate range. Finishing pigs in a cold environment eat more because their maintenance energy requirement is increased to maintain body temperature. Growth rate may not be affected, but poorer feed efficiency results in general. However, severely cold stressed pigs may not grow because they cannot consume sufficient amounts of energy above their maintenance requirement. There is a difference in the additional feed needed per °C of coldness between grouped pigs and those kept singly. Those in groups can huddle, thereby reducing body-surface exposure and heat loss to the cold environment. One can conclude that a pig weighing 20 kg should consume additional feed at the rate of 13 g/day/°C of coldness, and for pigs weighing 100 kg up to 35 g/day/°C. Extra feed intake is required during cold to compensate for reduced gain in restricted-fed pigs. Fat, protein, water, and ash gains, which together comprise body weight gains, may be reduced in several ways. Fat gain will be more reduced in the cold than protein gain, because fat is used primarily as fuel (Masoro 1966). In growing pigs, the same has been found by Hacker et al. (1973), Verstegen et al. (1973), and Brown et al. (1976). Close and Mount (1976) showed that reduction in protein gain in the cold is dependent on feeding level. Verstegen et al. (1978) concluded that average daily gain is depressed by 15 g/°C of coldness when feed intake rate remains constant.

8.6 Nutritional Management of Transportation Stress

Transportation of food animals for different purposes results in stress with substantial physiological changes in the body. Transportation can combine with a number of physical and psychological stressors, such as stress of loading and unloading, huddling of unfamiliar animals, loud noises, feed and water deprivation, extreme temperature, and new housing environment can be stressful. For that some basic managemental practices need to be followed. Provision should be made for care of animals during the journey and at the destination. Particular care should be taken with animals that are fatigued, old, young, infirm, pregnant, and/or nursing. Animals should be neither too loosely nor too tightly loaded so as to reduce the risk of excessive movement or overcrowding resulting in injury. The distance animals are transported, and the time taken, should be minimized. During transport animals should be protected from extremes of heat and cold and provided with adequate ventilation. Where livestock are transported over long distances, appropriate provision needs to be made for feeding and watering of the animals. The foremost essential nutrient is water, and has to be made available as temperature of the transport environment generally increases.

During transportation most of the animals react to the experience by becoming anorexic and adipsic. The stressful experiences of a novel environment, movement of the transportation vehicle, food and water sources that differ from those in the animal's previous environment for logistical reasons inhibit food and water consumption. The most appreciable change observed in farm animals that are being transported is loss of body weight, which is more rapid when transported than it would normally occur without feed and water. This consequence implies that transportation is stressful for reasons beyond the lack of feed and water. Provision of feed or water during transportation can be problematic because of food spoilage and water spillage; wetting of the floor by spilled water, which results in chilling, slipping, and injuries; animals' lack of ability to eat or drink while in motion; motion sickness; and lack of motivation to eat or drink during the trip. Thus, providing food or water may not be of any benefit during short trips because of lack of motivation to consume food and water.

Provision of feed and water during very long trips requires special attention, especially if the vehicle stops or has periods of stability during which animals may seek food and water. In cases where an animal may refuse food because it is presented in a novel form or source, animals should be adapted to the travel and post-travel diets and to feed and water dispensers before travel. Exposure to the food forms and water sources that will be used during travel before the trip may help to reduce dehydration and weight losses during transportation.

Water is the most important consideration for trips of intermediate length for most species. Small animals lose more heat, require more calories per unit of body mass, and become dehydrated more quickly than larger animals. Xin and Lee (1996) found that the provision of water (or a substitute) and feed were also important for sustaining day-old male chicks during long trips. Transportation stress in poultry impairs normal body functions, leading to increased morbidity and mortality, poor meat quality, and decreased productivity (Fazio and Ferlazzo 2003; Fallenberg and Speisky 2006; Franco-Jimenez and Beck 2007; Rozenboim et al. 2007). When poultry birds are huddled during transport, the combination of high ambient temperature and relative humidity provokes heat stress and the excessive generation of reactive oxygen species (ROS) or free radicals (FR) takes place as a result of increased metabolism in birds (Ramnath et al. 2008). Normally, non-enzymatic antioxidants, such as vitamin C, produced in the bird's kidneys, are involved in the elimination of excess FR or ROS from the body, but under praxis condition, they are either exhausted or overwhelmed; thus, exposing cells to their harmful effects (Maurice et al.

2002). Thus in such situation supplementation of vitamin C and E may prove beneficial in alleviating transportation stress in hot weather (Ajakaiye et al. 2010). Pigs are also quite susceptible to transportation stress and meat from such stressed pigs has bearing in meat quality (Tarrant 1989). In such situation sedation of stressed animals may be done, but such practices are not allowed in modern food industry due to residual effect in the food chain. Thus, alternative feed additives such as tryptophan, vitamin E, and herbal products can prove as an alternative to counter transportation stress in pigs (Peeters et al. 2004), thereby improving both their welfare and their meat quality without introducing a residue risk for food safety.

8.7 Conclusion

Stress is inevitable in livestock production system. In general it has adverse effect on livestock production and huge economic losses are sustained by farmers. Understanding of stress at mechanistic level and the different interaction of farm animals with environment will help in developing suitable strategies to overcome the adverse effect of stress in farm animals. Nutritional management of stress, however, will be helpful in overcoming the detrimental effect, provided sound knowledge of nutritional requirements of farm animals at different age, production level, and seasons are amalgamated in a holistic manner. Further, research works are needed to find the nutritional requirement of stressed animals in rapidly changing climate scenario.

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